Renewable and Sustainable Energy Reviews 27 (2013) 453–463

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Status of renewable energy consumption and developmental challenges in Sub-Sahara Africa

Y.S. Mohammed [a,*], M.W. Mustafa [a], N. Bashir [b]

[a] Department of Electrical Power Engineering, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Johor Baharu, Malaysia
[b] Institute of High Voltage and High Current, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Johor Baharu, Malaysia

ARTICLE INFO

Article history:
Received 9 August 2012
Received in revised form
27 May 2013
Accepted 28 June 2013
Available online 1 August 2013

Keywords:
Renewable energy
Sub-Sahara Africa
Challenges
Development

ABSTRACT

Energy use is a prerequisite for physical and socio-economic development in both rural and urban communities. There is a need to promote and guarantee energy security, availability and reliability to preserve any existing level of development and further new developmental strides for human comfort. Access to modern energy is considered one of the foremost factors contributing to the disparity between developed and developing nations. Undisputedly, Sub-Saharan Africa (SSA) is the most physically and economically backward developing and poverty-stricken region in the world. The slower rate of development can be attributed to the low access to modern energy use in the region as a result of a high level of constraints ensuing from underprivileged energy policies, inadequate funding, ineffective energy infrastructures and the low pace of technological diffusion. These overlapping deficiencies are responsible for the looming scenario of energy crisis in the region, which has heightened the degree of dependency on combustible renewable energy sources for primary energy consumption. The application of modern renewable energy is a negligible component in the regional power sector compared with its naturally endowed potential. This review presents the current state of affairs of renewable energy application in SSA. From a focal point of view, wind energy, solar energy, hydropower, bioenergy and geothermal energy are fundamentally discussed within the framework of socioeconomic and technological developmental challenges in this review article. It was stressed that combustible bioenergy is excessively consumed in the region especially in the rural segment of society. It also pinpoints some prevailing challenges negatively influencing the development of renewable energy using modern technologies. Conclusively, this research highlights the need for effective international and cross-sector collaboration on inputs from financial, resource and technological development mechanisms for renewable energy exploitation.

Contents

* Corresponding author. Tel.: +60 101 673 13271; fax: +60 755 662 72.
E-mail address: engryek88@yahoo.com (Y.S. Mohammed).

1364-0321/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2013.06.044

1. Introduction

The Sub-Saharan Africa (SSA) region is at the moment engrossed in the mesh of an energy crisis and undisputable socio-economic deficits. The region accommodates 13% of the human population in the world [1]. Access to modern energy in SSA has been time after time ranked underprivileged and the region was said to have occupied the last position in terms of growth in gross domestic product (GDP) and contemporary developmental strides. SSA is the least developing sub-region of the world with a very high number of dispersed rural settlements. The scattered nature of the rural settlements is responsible for the sub-region being technically and economically weak in achieving substantial grid connection development in the power sectors of many countries in the region despite the continuous increase in electrical energy demand. Between 1980 and 2007, world energy consumption grew by 5.4% while that of SSA grew by 1.54% with the regional countries' consumption accounting for only 2% of the world total [2]. Approximately 30% of the population in the region has access to electricity [3,4]. It is apparent that the nominal potential of renewable energy in SSA is great but the sustainable political will and enthusiasm to enact the regulatory framework for exploitation through modern techniques is low. This disparity is explained in more detail in Table 1 [5], which expresses the annual production potential of renewable energy (RE) relative to the present annual domestic energy consumption in the majority of countries in SSA.

Furthermore, in urban areas where the government has focused more attention on the delivery of electricity services to consumers, many households are subjected to underserved conditions, a problem resulting from supply system constraints and insufficient generation. Most urban areas in SSA have a very low percentage of electricity connection access due to the high price of fossil fuel electricity, unregulated tariff mechanisms and poor subsidy packages. In the last few years, some countries in the region, though limited in number, have made remarkable steps forward in providing access to electricity. In 2008, household access to electricity in Mauritius, South Africa, and Ghana stood at 100%, 70%, and 56%, respectively [6].

The majority of people in SSA exceedingly depend on biomass especially combustibles for primary energy generation for domestic cooking and heating purposes. Combustible renewable energy resources especially charcoal, wood fuel, dried crop and animal residues have some environmental effects due to incomplete combustion. Charcoal and firewood produce emissions but they are lower in charcoal compared to firewood stoves [7–9]. These combustible bioenergy sources are used in traditional stoves with no provision for direct or indirect indoor air pollution control. Low combustion efficiency is another characteristic of the stoves although presently technical efforts are being harnessed for improvement. The degree of success has reportedly varied with the ability of designers to alter some design parameters and the introduction of new design concepts.

Recent increases in the atmospheric concentration of greenhouse gases (GHGs) have renewed concerted interest in renewable energy to safeguard the environment. Exploitation of renewable energy (RE) sources is one of the most prevalent and suggested strategies to mitigate the impacts of climate change [10–12]. In many countries worldwide, national administrators in cooperation with international communities have been making rigorous efforts to moderate the discharge of greenhouse gases (carbon dioxide, methane, carbon monoxide and others) into the atmosphere. A report by the International Energy Agency (IEA) [13] stated that in 2005, 68% of total anthropogenic GHG emissions were obtained from energy related-activities. Improving electricity access in SSA has become a serious aspiration for regional stakeholders, which is in concert with global efforts towards rapid transformation to renewable energy supply. Currently, there is the potential for

Table 1
Annual production potential of RE to current domestic energy consumption.

Country	Total	Country	Total	Country	Total
Namibia	100.5	Burkina Faso	15.9	Kenya	6.5
Central African Republic	90.9	Madagascar	14.6	Malawi	6.4
Mauritania	86.2	Guinea-Bissau	14.2	Ghana	5.7
Chad	77.3	Tanzania	14.1	Uganda	3.1
Mali	58.4	Cameroun	12.7	Gambia	2.7
Niger	50.4	Senegal	12.5	Burundi	2.2
Congo	43.6	Benin	12.5	Nigeria	2.0
Angola	27.9	Sierra Leone	10.1	Swaziland	1.6
Sudan	27.6	Cote d'Ivoire	9.6	Lesotho	1.4
Zambia	25.2	Eritrea	9.5	South Africa	1.3
Congo Dem. Republic	24.7	Guinea	9.0	Equatorial Guinea	0.9
Mozambique	23.4	Togo	8.9	Cape Verde	0.9
Botswana	22.4	Ethiopia	8.5	Rwanda	0.7
Gabon	20.3	Zimbabwe	8.0	Comoros	0.2

transition from a high to low carbon regime, which is known as clean energy development. In this regard, this paper reviews the current status of renewable energy consumption in SSA and discuses some theoretical issues negatively influencing the development of modern techniques for renewable energy exploitation in the region. Renewable energy policy intercessions in the region are also discussed within this review article.

2. The role of energy in the development of a society

2.1. Energy in a progressive society

Development may occur in the form of physical infrastructural transformation, technological acquisition and human capacity building purposely undertaken to sustain modern comfort and foster the socio-economic development and globalisation of human societies. All forms of development can be achieved sustainably provided that there is adequate and sustainable interaction among energy sources, human beings and society. Interactions for constructive development of any sort require modern energy and, more specifically, electrical energy. Judging from present day efforts to reduce human labor while maximising productivity, electrical energy is a turning point for all forms of modern development. An existing consensus exists in both scientific endeavours and community development advocacy on the role of energy as a catalyst for development at the global, national and local levels [14]. Significantly, on a global scale, energy relationships have been established to meet the objectives of the millennium development goals (MDGs) [15,16].

Toman and Jemelkova [17] stated that energy as a component in production functions is a productivity enhancing factor. In most urban areas, large business investments presently rely more on fossil fuel-based large power generation. In contrast, rural industries are small and micro-scale enterprises with lower electricity consumption from the operation of distributed generation systems. They are usually established for improving the socio-economic living standards of rural inhabitants. If rural energy systems continue to be dominated by too much unprocessed biomass production and consumption, as well as inefficient energy options, the essential conditions for social, economic, and ecological advancement in rural areas will continue to be in a state of constriction [18].

There is a very close linkage between energy and development. Energy policy and strategic planning can favorably converge with any form of development (Fig. 1) provided the two concepts are premeditated to achieve resource diversification. Therefore, a dearth of commercially supplied energy in a society, in particular electricity, tends to heighten the existence of social asymmetry in living conditions [19] and limits opportunities for modern development. It is a widely accepted standard that with the presence of electricity, societies are more likely to acquire a privileged level of economic sustainability and improved quality of life [20]. Among the developing nations of Southeast Asia are countries like India, Malaysia, Singapore and China that are benefiting from a positive economic outlook and significant poverty reduction due to increased access to electricity.

Sub-regional economic sentiments exist generally in Africa and particularly in SSA due to the economically diverse nature of the continent and sub-region. This is why there is a substantial difference in the access to electricity between North Africa and other regions (east, south and west) collectively known as Sub-Saharan Africa. As presented in Fig. 2 [19], it was estimated in 2008 that 589 million people have no access to electricity in Africa while 587 million corresponding to 98% of the total population reside in SSA. Thus, the overall electrification rate remains low in the region compared to other developing countries. The demand for electricity in the SSA will continue to grow due to population increases and the quest for socio-economic advancement in the region to improve the standard of living.

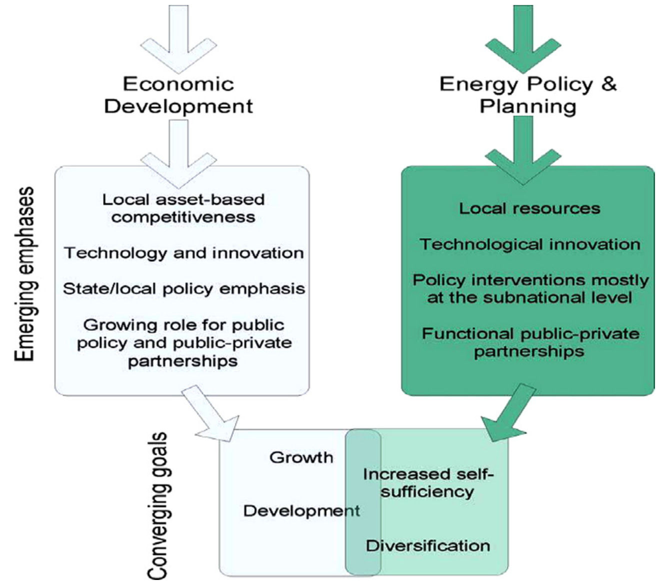

Fig. 1. Parallel evolution and converging goals in the fields of economic development and energy policy and planning [18].

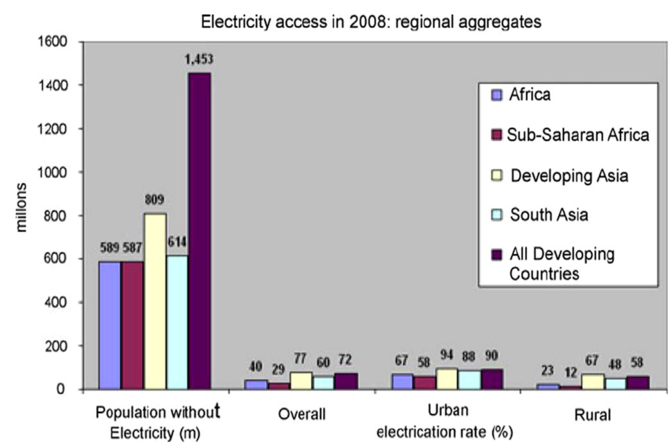

Fig. 2. Electricity access in developing countries [19].

2.2. Rural electrification factors for diffusion of innovation in developing countries

The conception of rural electrification is imperative for social and economic growth in rural areas with the prospect to improve the quality of life of rural inhabitants by providing electricity for the lighting of homes, business centers and public places in the rural domains [21]. In many parts of the world, rural electrification is fast becoming a well-known development. In recent years, many researchers of small energy projects, especially those with specialisation in RE implementation, have focused on rural energy design and implementation as well as financial modeling. Although RE innovation is historically concentrated in developed countries, in developing countries it is progressively more prevalent in powerful emerging economies [22] as well as the recently developing countries of Africa [23,24].

Different means of electrification have been used for rural electrification in developed and developing countries. In some

cases, a single RE source has been used while others prefer a combination of different RE systems for exploiting economic advantages. At times, a suitable combination of conventional energy systems with RE is also possible to lower the cost of electricity generation and emissions. In power systems, this methodology of rural energy provision is called hybrid power systems. Many case studies on rural electrification have investigated the feasibility of using single energy [25–28] and hybrid power systems [29–36]. In today's practice, irrespective of the methodology used for rural energy supply using RE systems, the provision of RE is based on the diffusion of innovation. To promote effective RE diffusion in a rural community, there is strong need to properly assess the following issues:

- Structural education and extension programmes that could lead to the adoption of innovative technologies in rural communities.
- Sustainable investigation of RE options for meeting the rural energy demand in accordance with the availability of RE resources.
- A concrete financing system as an integral prerequisite for successful project uptake.
- Enhancement of a quality control mechanism, operation and maintenance and system reliability for sustainable management.
- Possibilities for future system expansion to cater to growth in load demand.
- Methodology for tariff collection without jeopardising the economic objectives of the project or the paying capacity of the rural electricity users.

3. Current uses of renewable energy in SSA

The majority of electricity networks in SSA are weak in performance and technically unstable resulting from aging facilities. The winds of electricity deregulation, which is really making progress in Europe among other fast developing economies, is unremarkable in SSA. The reason is that most of the countries in the region incline to monopolistic conceptions regarding power market operations. This has negatively affected the performance of the power sector in the region. The characteristic problems usually occur in the form of a low availability factor of electricity, soaring losses in power systems, poor diversification of energy resources, sporadic power failure ensuing from ineffective reliability and inadequate funding systems. Increases in population and demographic expansion have greatly contributed to the recent rise in the level of energy demand in the region of SSA. While more attention is concentrated on biomass fuel and charcoal, other renewable sources like solar, wind, hydro and geothermal are being used in lower amounts in some of the regional countries.

3.1. Bioenergy sources

Biomass is one of the prime sources of renewable energy in SSA [37,38] and predominantly used by low income earners. Biomass consumption in SSA varies from country to country depending on the national access to electricity, resources availability and renewable energy policy. The rate of biomass consumption in SSA cannot be likened to any other renewable energy sources because biomass is considered the most easily acquired energy resource available for people from substandard economic backgrounds. The exploitable biomass energy in SSA principally comprises domestic waste, forest tree resources, animal residues, crop waste, waste paper materials, wastewater and industrial biodegradable waste. Data regarding the total quantity of exploitable biomass in SSA is not documented since the region is not fully committed to renewable energy development but instead has applied traditional techniques of bioenergy exploitation. In a more recent study conducted by Dasappa [39], the power potential was estimated to be 5000 MW from just 30% of agricultural residues and 10,000 MW from 10% of forest wood. The total sum of 15,000 MW estimated in the study is equal to 100 terawatt-hours (TW h), which is the equivalent to 15% of the current electrical generation capacity of the region. A total of 75.20 terajoules (TJ) was estimated from crop residues with proven potential capacity in Ghana [40] and 697.15 TJ for Nigeria. In Tanzania, biomass use forms more than 90% of energy consumption; also it continues to dominate as the main source of energy [41] compared to petroleum (12%) and electricity (1.2%) [42] due to the high cost of modern energy resources. In 2007, the energy balance in Ghana revealed that biomass accounted for 64%, while petroleum and electricity have a 27% and 9% share, respectively. In Uganda, a yet to be used potential of agricultural residues of 2600 MW exists [43].

3.1.1. Biogas

Biogas is a mixture of gases generated from anaerobic digestion of the organic fraction of solid waste (OFSW). It is a very clean source of energy especially for cooking judging from the emission point of view in comparison to kerosene and LPG-stoves. The main component and useful gas in biogas is methane, which is a highly combustible substance with high-quality calorific value. Biogas production is significant in controlling and collecting organic waste and fertilizer production for agriculture [44]. It entails translating different waste substances such as animal residues, wastewater, crop waste and municipal solid waste into biofuel production for energy. A single biogas substrate can be used separately or co-digested with others. Co-digestion of biogas feedstock is usually considered advantageous in a large community where a single biogas plant can be operated for economic benefit rather than constructing several independent bio-plant digesters.

In SSA, biogas sources are abundantly available but development is confronted with several challenges. The foremost restraining factors of biogas programs are the high capital investment expenditure, minimal practical demonstration, technical problems and cultural issues [45–47]. In scores of SSA countries, small- and medium-sized biogas digesters have been domesticated especially in rural communities to serve different energy purposes. The prevailing economic challenges in rural SSA have compelled users to exploit locally available resources such as clay, bricks and plastic polythene materials for the construction of the digesters. In addition, access to processing water in SSA is more of a problem than anticipated [48] because most rural and urban communities have difficulty maintaining sufficient water supply.

Biogas is fast becoming a close substitute to kerosene and LPG fuels in a region where it is well developed for use. To effectively promote the use of biogas in the region especially at this moment when the transition to green energy production is understood to be necessary, resources should be committed to the development of community-sized biogas plants and the opportunity for incentive provisions from the government should be enhanced. This strategy was recently observed in Pakistan. With pragmatic interest, the Pakistan Council of Renewable Energy Technologies (PRET) has installed 1200 biogas plants throughout the country on a cost-sharing basis, where 50% of the cost is borne by the beneficiary [49]. Most importantly, animal and human waste are used more often for biogas production in SSA while the application of the organic fraction of municipal solid waste is limited. In SSA, anaerobic digestion technological development, which benefits from abundant biogenic feedstock, is still in a premature stage. Only a few

research-based organisations like the Industrial Research of the Council for Scientific and Industrial Research (CSIR-IIR—Ghana), Kigali Institute of Science, Technology and Management (KIST-Rwanda) and Energy Commission of Nigeria (ECN) are prominent in their efforts towards renewable energy development in the region. There are a few other up-and-coming renewable energy research institutes, though they are not well-known.

KIST in 2003 installed large biogas digesters with a capacity of 830 m^3 and 1430 m^3 in 2005 situated around prison yards to be used as human waste generated as feedstock for biogas methane production. Biogas generated is in turned used for cooking within the same prison establishment. In Tanzania, a 23,000 m^3 biogas methane project was initiated by the Global Environment Facility (GEF). In Ghana, Appolonia Village is already generating 12.5 kW of electric power using biogas obtained by co-digestion of animal and human waste within the locality.

3.1.2. Agricultural crop biomass residues

SSA is one of the regions in the world with substantial potential for cereal crop production. Residues linked with agricultural production, which are sometimes discarded after harvest as on-the-farm wastes, can be used as good sources of biomass for power generation. The most commonly used agricultural residues in the region are tabulated in Table 2. Currently, these residues are burnt after harvest and a very low quantity is used as domestic fuel to supplement the shortage of firewood most especially in open forest sub-regions. Using appropriate crop-to-residue conversion ratios, the total residue production quantity can be obtained from the annual crop production statistics for a theoretical estimate of energy potential. The energy potential of each residue depends on the calorific value. These residues may be converted to energy by thermo-chemical or bio-chemical processes. Significant potential for energy crops such as cassava, *Jatropha curcas*, castor oil and palm oil fruit for liquid biofuel production are also present in the region.

Nigeria is a leading producer of oil palm fruit production in SSA but there is very little interest in its use in biodiesel production. In the world market, Nigeria represents a 3% share of oil palm production [40]. Ghana has approximately 320,000 ha of oil palm plantations [50]. Besides the existing liquid ethanol production in South Africa, biodiesel development in the Eastern Cape Province of the country has been recently structured by the government under the project name: Accelerated and Shared Growth Initiative for South Africa (ASGI-SA). It plans to utilize canola as a feedstock with a production capacity of about 400 million metric tons of biodiesel [51]. Other countries in the Sub-Sahara region have reasonable potential for either bio-ethanol or biodiesel production as shown in Table 3. The region produces biofuel below the actual potential and thus there is an urgent need for an effective policy bailout to accomplish the envisioned target of the biofuel substitution program by the year 2020.

Table 2
Major crops grown in SSA and their biomass residues.

Crop	Residue	Crop	Residue	Crop	Residue
Paddy	Straw	Groundnut	Shells	Millet	Stalks
Paddy	Husk	Palm fruit	Empty bunch	Mustard	Husk
Paddy	Stalks	Sorghum	Stovers	Mustard	Stalks
Maize	Cob	Wheat	Straw	Tobacco	Stalks
Maize	Stalks	Sugarcane	Baggase	Sunflower	Stalks
Coconut	Husk	Coffee	Husk	Soyabeans	Stalks
Groundnut	Stalks	Cocoa	Pods, Husk	Peas and beans	Stalks

3.1.3. Forest bioenergy resource

Biomass has the largest potential to meet fuel supply in the future [55]. Forest biomass is one of several potential sources of biomass which in addition to its higher energy density has sustainable potential that varies from region to region depending on climate conditions. The forest in SSA is rapidly undergoing degradation compared to other regions in the world. SSA had a share of 12.7% of the total world forest in 2005 (Table 4). Forest biomass resources include wood, branch cuts, tree trims, wood stump and dead trees. Around 94% of rural and 41% of urban households use wood as their primary source of domestic energy whereas 4% of rural and 34% of urban areas rely on charcoal in SSA [56]. Fuel wood is chosen by households based on the income spectrum as a strategic energy source imperative for specific applications [57].

Clearly, a lot of people in the region depend on forest resources for firewood or charcoal production. This is a very worrisome practice for environmental sustainability because a very large percentage of the regional forest has been lost and the opportunity for the emergence of a new natural forest is highly constricted. It has been exacerbated?? in the form of destruction of natural wood plants and shrubs in their early state of succession because young trees can easily be harvested in view of the tedious labor involved in cutting down trees by women and children. In Nigeria, for

Table 3
Selected countries with major biofuel production potential in SSA [52–54].

Country	Raw material	Biodesel ([d]ML)	Ethanol ([d]ML)
Benin	Cassava	–	20
Burkina Faso	Sugar cane	–	20
Ivory Coast	Molasses	–	20
Ghana	Jatropha	50	–
Guinea Bissau	Cashew	–	10
Mali	Molasses	–	20
Malawi	Molasses	–	146
Kenya	Molasses	–	413
Ethiopia	Molasses	–	80
Niger	Jatropha	10	–
Nigeria	Sugar cane	–	70
Sudan	Molasses	–	408
Swaziland	Molasses	–	480
Senegal	Molasses	–	15
Tanzania	Molasses	–	254
Togo	Jatropha	10	–
Uganda	Molasses	–	119

[d] ML=megalitre.

Table 4
Distribution of forest by sub-region 2005 [61].

Region/sub-region	Forest are (1000 ha)	% of Global forest area
Eastern and Southern Africa	226,534	5.7
Northern Africa	131,048	3.3
Western and Central Africa	277,829	7.0
Total Africa	**635,412**	**16.1**
East Asia	244,862	6.2
South and Southesat Asia	283,127	7.2
Western and Central Asia	43,588	1.1
Total Asia	**571,577**	**14.5**
Total Europe	1,001,394	25.3
Caribbean	5,974	0.2
Central America	22,411	0.6
North America	677,464	17.1
Total North and Central America	**705,849**	**17.9**
Total Oceania	206254	5.2
Total South America	**831,540**	**21.0**
Total world	3,952,025	100.0

example, about 350,000 ha of forest and natural vegetation are lost annually to firewood harvest, illegal logging, mining, seasonal fire and unsustainable farming practices such that the rate of aforestation is just 50,000 ha per year [58]. Similarly, a report by Dukan et al. [40] stated that between 2000 and 2005, 115,000 ha of forest were lost in Ghana, though the country has a small land mass and is approximately one-sixth of the population of Nigeria.

Renewable energy policy in South Africa seeks to generate 15% of the total energy generation mix from renewable sources [59] but with less emphasis on forest biomass consumption to preserve the natural environment. Despite the better access to electricity in the country, quite a large number of rural dwellers in the country still depend on fuel wood and charcoal especially for cooking and heating due to the high cost of electricity. In SSA, the South Africa electric power industry uses more coal for power generation and to some extent other fossil fuels. Coal presents 75% of total fossil fuel utilisation and 91% of electricity generation [60]. A similar effect on excessive forest bioenergy consumption is seen in Malawi, Burundi, Mali, Kenya, Senegal, and specifically in Uganda where access to electricity is as low as 5%, and thus forest biomass is predominately relied upon for domestic energy supply in the country.

SSA has more rich forest resources in the central, southern and western sub-regional part of Africa. Wood wastes from lumber and furniture making industries are other important bioenergy sources that can be found in the region. Different biomass stoves utilising wood wastes for domestic energy services are presently in use for thermal energy production. In Kenya, a locally improved biomass-stove (Kenyan Jiko) has been developed with a combination of earthen clay and metallic materials as shown in Figs. 3 and 4, which shows an improved wood stove developed in Malawi. Sawdust particles have been used to make briquette for increased burning efficiency. Wood wastes from sawmills have successfully been used with palm residue (empty fruit bunch) for briquette in many rural communities for cooking, tobacco curing, water heating and crop drying. In Ghana, a 6 MW cogeneration facility operation on a mixture of sawdust and palm residue has been reported by Dukan et al. [40]. The major drawback of sawdust applications is the emergence of other competing applications in recent times. Among the various biomass used in SSA, there is an urgent need to thoroughly check the use of biomass resources to prevent desert encroachment and land degradation, which is another potential source of the increase in environmental disasters.

Fig. 3. Charcoal stove (Kenyan Jiko) made of clay/metal, artisanal production, Kenya [62].

3.2. Solar energy sources

Solar energy is an energy source that can reinforce energy security in a region where it is sufficiently available. Energy from the sun has the ability to promote socio-economic gain if it is well harnessed. Solar power is a form of energy generated from the effects of solar radiation created from a positive enthalpy change in the solar body, which is propagated in a waveform through the phenomenon of solar thermal radiation. It can be exploited by using special solar-energy capturing sensitive devices such as photovoltaic panels to convert the energy generated by the solar body into electrical energy. Solar energy has not been adequately exploited compared to its naturally endowed potential in SSA. Across Africa, solar energy potential is unevenly distributed across the region but the intensity of solar radiation (varying between 4000 and 7000 Wh/m^2) in the SSA region is potentially capable of sustaining the needed domestic electricity to power home appliances [Fig. 5]. In the entire region of Africa, solar irradiation at all sites was higher than the typical daily domestic load requirement of 2324 Wh/m^2 in urban and rural areas [63]. In a number of SSA communities, the application of solar power is used more in solar-roof PV collectors for water pumping, domestic lighting, public closed circuit television (CCTV) systems, road junction automatic traffic light control systems, solar power community lighting and water heaters in a few places. It is also used in a limited number of urban street lights. These current applications are still employed on a small-scale compared to the large desert area of the region with immense potential for beneficial development. Grid connected PV distributed generation has been on the rise in the last few years throughout the world (Fig. 6), especially among developed countries and the Southeast Asian countries.

Fig. 4. Wood stove (Institutional Rocket Stove), made of metal and insulation material, artisanal production, Malawi [62].

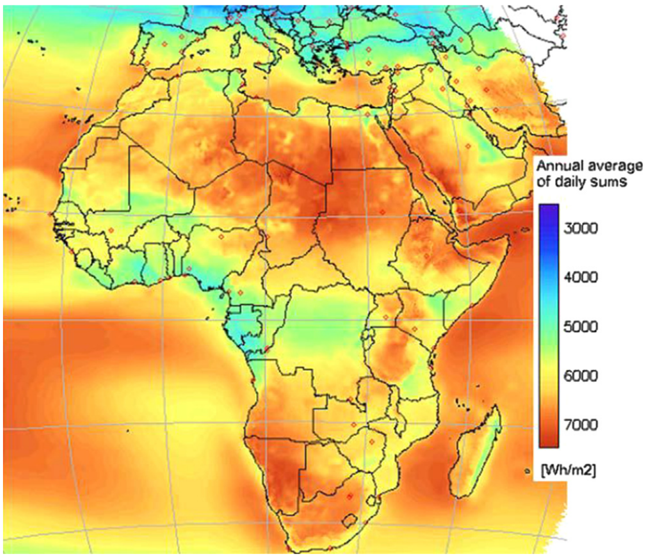

Fig. 5. Solar map of Africa [64].

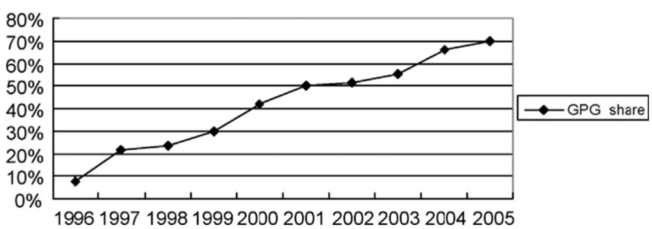

Fig. 6. Rising share of GPG in the world (*Source*: International Energy Sources Office, PV item bulletin in 2006) [65].

In sharp contrast, many developing regions have yet to make the expected gains in the incursion of PV systems into their national power generation mix due some complex and integrated factors. A few developing countries have demonstrated their passion for solar power exploitation. In China, Dunhuang of Gansu Province, a 10 MW grid-connected solar power plant has been implemented; a 1 MW plant in Shanghai and about 225 kW in Neimenggu Province were also realised. The regional government of SSA is making serious efforts towards using solar energy in response to current rapid rises in the price of fossil fuel energy. The economic and environmental intrinsic worth of solar energy are generally acknowledged throughout the world. However, unsuccessful policy mechanisms as well as financial barriers are among those factors affecting the development of solar power consumption in the region. Solar power applications are one form of renewable energy that private individuals have a strong quest to use to satisfy their energy demand but the initial capital uptake required is one of the major challenges for the majority of households in the region, bearing in mind the pervasive financial problems as a consequence of mass unemployment and the characteristic low wage scenario in the region.

3.3. *Wind energy source*

Wind energy is one of the major renewable energy resources with the potential to meet the rising energy demand and to some extent, guarantee the security of the global energy supply, especially in arid and cold regions of the world. Wind energy applications have played a very significant role in designing nearby sustainable energy solutions for some geographically secluded rural villages. It has also been used for detailed perception of the dynamics of energy provisions and utilisation within some remote communities. Globally, the cumulative and annual capacity of wind power has consistently been on the rise (Fig. 7). The global potential rose from 6100 MW in 1996 to 94,000 MW in 2007 [66]. This remarkable global growth in wind power technology development has had a major contribution from Europe, which has seen the fast development of wind power technologies in the last decade, and now is leading the large-scale market [67]. The development of wind power in any part of the world needs to be influenced by strong government policy. In contrast, frail renewable energy policies and implementation in the SSA region are among the factors retarding efforts to propel the exploitation of wind energy in the region. No doubt, renewable energy technologies remain in an embryonic stage in their development in SSA as the general sluggish pace of technological diffusion in the region serves as a major hindrance to wind power development.

At present there is no strong supportive mechanism for the promotion of wind power development in the region but micro-scale consumption of wind power has been utilised in several remote villages of some countries in the region. Wind power systems installed are widely used for water pumping while a few countries use it for powering domestic appliances, especially in Ghana, South Africa, Nigeria, Kenya and Mali. Regarding commercial wind power system development, researchers are working on the assessment of the sustainability of the off-grid delivery model by experimentation with isolated mini-grid wind power renewable energy systems. In some developing countries of South Asia, small-scale enterprises are noted for concerted efforts to deliver micro-energy to isolated communities; thus, wind power can offer a useful opportunity.

3.4. *Hydropower sources*

Hydroelectric power generation captures and converts the kinetic energy of flowing water into electrical energy. It is the cleanest renewable energy source with the ability to preserve the natural quality of the surrounding air. Small and large hydroelectricity are presently used in the region but energy experts argue that large hydropower systems are preferred from the perspective of the unit cost of energy delivered compared to small hydropower schemes. Fig. 8 shows the spread of large dams across various countries in SSA. This is an indication that the region has strong hydropower potential if well tapped. The consciousness to adequately develop sustainable energy systems in the region to meet the growing energy demand has indeed impelled initiatives of the regional government of some countries to invest in hydropower programs.

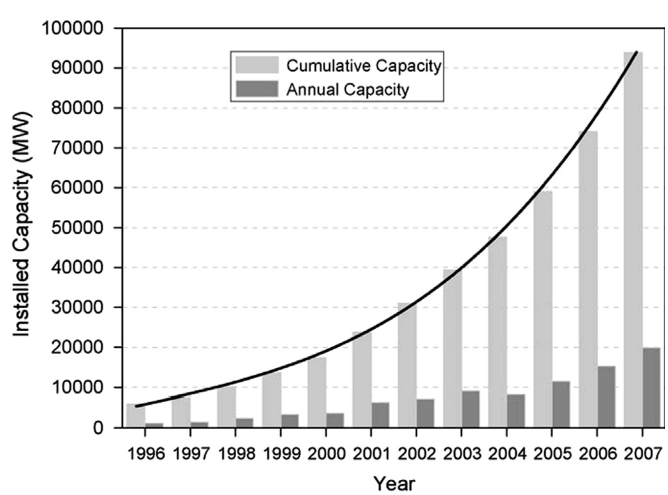

Fig. 7. Installed capacity in global wind power market (1997–2007) [66].

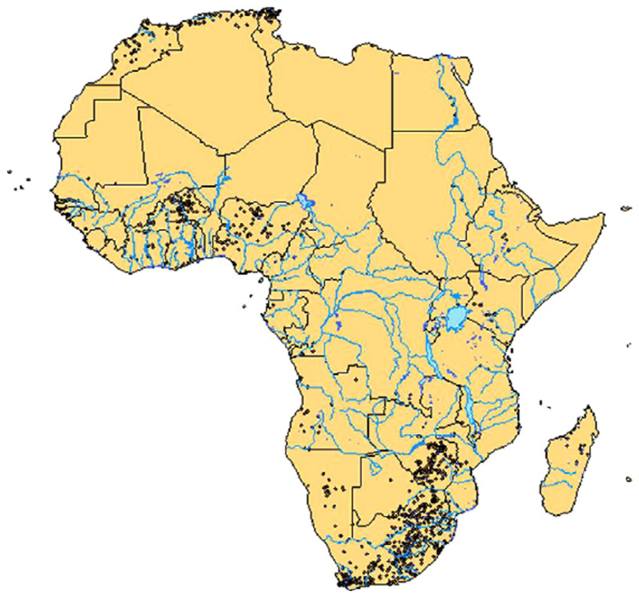

Fig. 8. Areas of large dams in Sub-Sahara Africa [68].

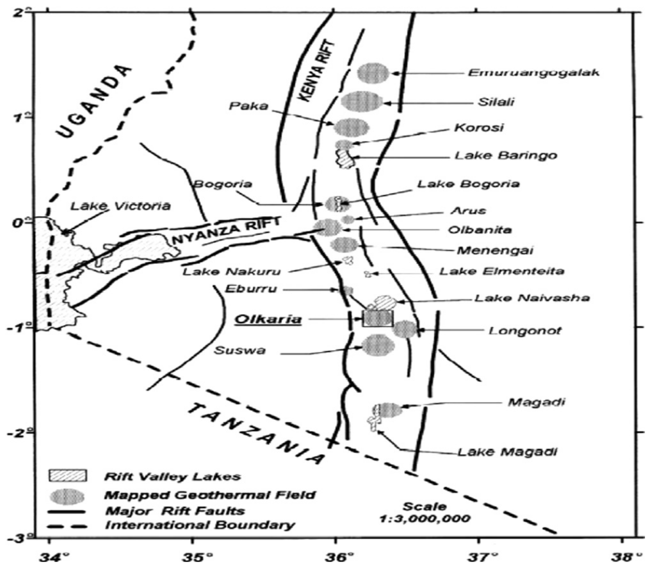

Fig. 9. Map of the Kenya Rift Valley showing areas of geothermal potential [69].

The potential of hydropower generation in each respective country of the SSA depends on the amount of precipitation of each country. Availability of water resources for power generation is mainly guided by seasonal variation. This strongly accounts for the variation in the run-off water and thus determines the potential output of hydropower as being the case experienced recently in the Nigerian hydropower sector. Dams for small and large hydropower are built across different places in the regions to store flowing water, which is used for power generation with the ability to offer the opportunity for changeable demand for electricity. Development of hydropower offers immense hope for providing solutions to the regional energy crisis, being that the water used is not subject to market price variation in the same way as oil and gas are.

3.5. Geothermal energy

Geothermal power generation is the process of converting the thermal energy from any geological structure on the earth′s crust to electrical energy. In the method of operation, the geothermal power plant is similar to that of traditional fossil fuel-thermal plants operating with steam turbines. The steam generated in the geothermal power system is obtained from natural sources (earth); contrary to conventional steam plants where the boiler is constructed to produce hot steam for running the plant. Currently, geothermal power in SSA is only visible in Kenya with the generation of 163 MW of electricity from four different sites in Olkaria. Apart from this geothermal site, the country is blessed with enormous geothermal energy sources spread across different locations in the region of the volcanic center in the rift valley as shown in Fig. 9. A study conducted on the potential revealed that between 4000 and 7000 MW of geothermal electricity potential has yet to be exploited in Kenya [69]. Private investors under the nation′s independent power projects (IPP) and government have been making anxious collaborative efforts towards exploitation of the available geothermal power resources in the country. In other SSA countries where the resource exists, they have not being locally or industrially exploited for meaningful renewable power generation. Exploration is still ongoing in many parts of the sub-region even in Kenya where this renewable source of energy is already manifesting its important role in the nation′s power sector.

4. Challenges facing renewable energy development in SSA

The starting point of sustainable energy technology transfer to mitigate the impacts of climate change from industrialised nations to the developing world is enshrined in Article 4.5 of the United Nations Framework Convention on Climate Change (UNFCCC) [70]. Both developed and developing countries are striving towards replacing certain quantities of their fossil fuel consumption with renewables to minimise their contribution to critical environmental issues. These efforts have been echoed in most reports with strong suggestions that there is need to facilitate the transfer of RE technologies to developing countries [71], which is the main idea behind the establishment of the clean development mechanism (CDM). CDM projects characteristically result in a transfer of GHG abatement technologies to developing countries in exchange for GHG emission reduction credits [72]. Realistically, the CDM project mechanism has been in existence for more than a decade but has yet to unfold its appreciable impact on developing countries based on its motive of technology transfer. In striving to meet renewable energy targets, developing countries have been confronted with some multifaceted challenges concerning renewable energy implementation stability to promote its development. The major challenges negatively influencing renewable energy development in SSA include the following.

4.1. Cultural constraints

Cultural background is one of the prominent factors with the potential to influence either the success or failure of a renewable energy project, especially in the SSA region with its diverse cultural heritage. Cultural adaptations of some ethnic groups have the potential to negatively influence the spread of renewable energy technology development. This is obvious in Kenya and Nigeria where people especially the rural dwellers prefer cooking at night and the development of solar cookers reportedly failed. In many rural areas where people are predominantly farmers, dinner is considered the most essential meal and the people are acquainted with the culture of cooking at night to prevent neighbors from knowing what they are cooking. The cooking activities are usually scheduled within the early hours of evening to the late night when no solar radiation to make a solar cooker is available. In most northern parts of SSA countries, seasonal winds prevail and people prefer constructing their traditional stoves

indoors to avoid contact with dust particles. This practice is also harmful health-wise since it is capable of increasing indoor air pollution, especially when combustible biomass is used.

4.2. Educational background

Education here is interchangeable with the concept of awareness. According to Van der Gaast et al. [70], there are large gaps in the level of understanding about the potential usefulness of renewable energy technologies. Generally, Africa has a high level of illiteracy compared to other parts of the world. The majority of people in SSA do not have the privilege to be educated and therefore the concept of modern renewable energy is largely unknown to them. Nor is proper orientation provided to the uneducated masses regarding the environmental and technical implications of the excessive use of combustible renewables, which is widely adhered to in the region. By repercussion, this has decelerated the rate of development, diffusion, dissemination and application of renewable energy infrastructure and technological understanding in the region.

4.3. Unstable economies and low levels of foreign investment

The general economic index of SSA has been rated low due to a low level of internal investment, limited diversification of natural resources, improper energy planning and gross financial mismanagement. Poor economic signals arising from the current global economic conundrum have indeed altered most of the world energy market as is typically visible in some underprivileged developing countries of SSA and South Asia. As earlier advocated in this study, energy transition activates different waves of developmental improvements with the tendency to consolidate economic and infrastructural investment progress. Since a great rural-urban energy divide exists in developing countries, governments can mobilise potential investors and business icons within and outside their countries to enthusiastically partake in the efforts to promote renewable energy application. If the renewable energy business can be adequately sustained through a feasible economic portfolio and improved foreign investment, the end users price can drastically fall in favor of consumers. This can in turn liberate rural communities from energy access difficulties. A new economic model can also be achieved provided that the non-tradable renewable energy commodities can be well utilised for fuel production and power generation.

4.4. Poor financial support and high interest on credit facilities

Renewable energy production is usually associated with high initial capital expenditures. Investment in RE technologies may produce energy output at a high cost to potential consumers compared to fossil fuel-based energy if not financially sponsored and subsidised. In this situation, financial arrangements either in the form of investment or user subsidies are inevitable. The absence of these financial supports is considered a great barrier to renewable energy development. In SSA, existing capital markets are not in favor of small-scale investment [73] which is usually a precondition for renewable energy development in remote areas. Credit facilities rarely exist for renewable energy investors and where they do, interest rates are high such that investors are not willing to embark on the high risk involved. Most energy investors have no proper knowledge of renewable energy development because adequate information regarding financial and technical prospects are lacking. Renewable energy subsidy arrangements have not been well organised in the region. Government support for energy has been limited to conventional power generation, but to exploit renewable power generation especially in rural communities there is a need for development and implementation of powerful subsidy policies especially for rural residential electricity services. It has been argued by Karakezi and Kimani [74] that removal of subsidies for conventional energy systems may not be politically and socially convenient; therefore, a reasonable approach stated by Kankam and Boon [14] has advocated that there should be deliberate policy choices that support an equal level of subsidies and other incentives for delivery and use of renewable energy options. Many subsidy scheme programs in operation in the region have seriously being affected by gross financial mismanagement, poor funding schemes and indecent planning.

4.5. Unsustainable renewable energy policy

It is understandable that different countries in SSA have unique national renewable energy policies while regional policies are immature due to the nature of their implementation approach. Several policies have been developed but the political instability in the region has made it difficult to implement them. Policy issues have become a major barrier to financial access and market development. The governments of most countries in the region operate decentralised forms of administration, and policies supporting mutual alliances between central and local governments have not been well established to support actual plans, programs and actions for renewable energy development.

4.6. Impracticable demonstrations, absence of core technologies and poor capacity building

The realistic demonstration of renewable energy technologies is considered essential in a region with a low level of education. From a pragmatic point of view, it is more convincing for people without access to modern education to believe in what they see physically rather than what is presented based on a theoretical approach. Core renewable energy technologies are either not available in many places or not well sustained in a few communities where they are present in SSA [23,24]. Human capacity building towards harnessing the sustainable potential of renewable energy resources is not well enhanced by the key stakeholders in the energy sectors in the various regional countries. To meet the electric power demand of a community, there must be a strong desire to develop and constantly update technologies for energy generation.

5. Regional bodies and renewable energy for rural development in SSA

Electrification in rural and isolated locations in SSA hardly attracts government attention due to the economic costs of traditional grid expansion lengthy distances and to scattered geographical settlements. Renewable energy distributed generation systems are now being considered as viable options for providing solutions to electricity scarcity in such areas. Various international communities supporting RE development have been advocating the need to reasonably reduce the number of people without access to electricity, which are mostly the inhabitants of South Asia and SSA. With respect to this call, several regional economic and development bodies have emerged in recent times, including the Economic Community for West Africa States (ECOWAS), Southern African Development Community (SADC), East African Community (EAC), Communaute´ Economique et Mone´taire de l'Afrique Centrale (CEMAC) and Union Economique et Mone´taire Ouest-Africain (UEMOA). Although these regional development communities are expected to play a very crucial role in the quest

for increasing access to energy in the region, until now they have yet to strike a remarkable level of achievement. In our candid opinion, to achieve noteworthy success towards increasing access to electricity in the region, these organisations need some level of cross-fertilizing cooperation both internationally and locally. The cooperation is an essential paradigm to disseminate existing technologies and transfer emerging types. China, India and other developing countries of the world are determined to achieve some level of development in renewable energy use but Africa in general still lags behind in the deployment of renewable energy technologies [75].

6. Renewable energy policy issues

The restructuring of electricity in the SSA has given birth to several national policy frameworks regarding distributed generation of electricity mostly in rural areas. In different countries of SSA, a number of policy actions have emerged in favor of renewable energy consumption. In some cases, the policy mechanism is structured to directly integrate renewable energy applications into the power sector so as to enhance power supply reliability, security and availability through the phenomenon of the clean development mechanism. This was adequately informed by the growing trend in the population and enthusiasm for socioeconomic solutions to the prevailing poor standards of living, which are typically rampant in the region. Strategic policies adapted to proffer solutions to renewable energy use in SSA include renewable energy portfolio standards, private sector participation in renewable energy investment and deregulation of the downstream oil and gas sectors to put the price of fossil-based energy above that of renewables.

Several regulatory agencies, private sector organisations and corporate bodies have been established to help boost interest in renewable energy application. The Energy Commission of Nigeria (ECN), Energy Commission of Ghana (ECG), Ghana Energy Development and Access Project (GEDAP), Capacity Building Project in Energy Efficiency and Renewable Energy (CaBEERE) in South Africa are well meaning energy development institutions advocating for renewable energy exploitation using modern technologies. Policy reform issues have been poorly implemented and this has sprinkled doubt as to whether the region would be able to achieve 100% access to electricity for all by the year 2030 and beyond. Out of the 47 countries of the SSA, less than one-quarter of the nations have electricity access above 45%. Without any doubt, various governments in different countries of the region are making keen efforts towards encouraging energy resources diversification to realise an improved energy generation mix as a pathway to attain energy supply security and sustainable development. These efforts will encourage renewable energy development in the region. To record a major breakthrough in renewable energy development, however, there is a need for reinforcement of existing energy policies and possibly the emergence of new ones which can advance a level playground for the penetration of renewable energy investors operating under the circumstances of sustainable market development.

7. Conclusion

In conclusion, it is obvious that the entire Africa region is naturally blessed with renewable energy resources and the SSA region is even richer from a sub-regional perspective. The poor state of renewable energy application highly rests on the poor level of technological applications and insufficient energy infrastructural development to cater to sustainable uses of resources. The SSA energy sector makes minimal use of fossil fuels and to some degree small hydropower (SHP) but extensively uses combustible bioenergy sources. In a situation of adequate planning to increase energy access, rural households can use modern day renewable energy technologies of micro-hydro systems, solar photovoltaic panels, and small-scale wind energy turbine infrastructure as well as biogas digesters for domestic energy consumption. These Res can effectively counter the uneconomical circumstances of connecting such remote villages to fossil-based conversional grid-powered electricity.

It is an undisputed fact that presently fossil fuels cannot be replaced absolutely with renewable energy resources either in developed or developing regions; therefore, domestic energy consumption for cooking can be enhanced using improved solid biomass and biogas cook stoves especially in rural growth centres. Although the stoves are already in use in some countries but not widely adopted due to a poor level of awareness, a weak market and shortage of technical experience and capital. Adequate dissemination and promotion approaches have to be sustained to educate the majority of people on the merits of the stove′s energy efficiency, fuel saving and the likelihood of indoor air pollution reduction with significant ability to lower health-related problems.

Adequate cross sector and international collaboration is also considered necessary to ensure the proper application of renewable energy. Nowadays, it is difficult to sustain research and development as well as capacity development without any external influence. For successful development of renewable energy systems, especially in this region with low technical educational, foreign assistance is highly inevitable. Policy advocating for cooperation a cross section between the energy sector on one hand and other important sectors in possession of renewable energy resources such as agriculture, environment and forestry needs to be developed. Wind, solar and hydropower sources are freely available; therefore, the financial sector and potential investors can be lobbied to invest in development. These initiatives will guarantee a significant change in energy access in SSA by ensuring that a multiplicity of renewable energy is available in the region and is adequately diversified to either provide energy access to all or reduce the number of people without access to modern energy. Since the majority of people affected by the energy poverty are peasant rural dwellers, strategies that can enhance better income generation in such areas should be supported to increase their energy purchasing capacity to create improved living conditions and economic potential.

References

[1] Kebede E, Kagochi J, Jolly CM. Energy consumption and economic development in Sub-Sahara Africa. Energy Economics 2010;32:532–7.
[2] EIA (Energy Information Administration), 2009. International Energy Annual 2004–2005. 〈http://www.eia.doe.gov/emeu/international/contents.html〉.
[3] IEA. World energy outlook 2006. Paris: International Energy Agency; 2006.
[4] WEC. Africa region report, energy policy scenarios to 2050.Study. London: World Energy Council (WEC); 2007.
[5] Buys, P, Deichmann, U, Meisner, C, That, TT, Wheeler, D. Country stakes in climate change negotiations: two dimensions of vulnerability. World Bank Policy Research Working Paper, no. 4300, August, Washington, DC; 2007.
[6] Brew-Hammond A, Kemausuor F. Energy for all in Africa-to be or not to be?! Current Opinion in Environmental Sustainability 2009;1:83–8.
[7] Bailis R, Ezzati M, Kammen DM. Mortality and greenhouse gas impacts of biomass and petroleum energy futures in Africa. Science (New York, NY) 2005;308:98–103.
[8] Koyuncu T, Pinar Y. The emissions from a space-heating biomass stove. Biomass and Bioenergy 2007;31:73–9.
[9] Smith KR, Uma R, Kishore VVN, Zhang JF, Joshi V, Khalil MAK. Greenhouse implications of household stoves: an analysis for India. Annual Review of Energy and the Environment 2000;25:741–63.
[10] Chien T, Hu J-L. Renewable energy: an efficient mechanism to improve GDP. Energy Policy 2008;36:3045–52.
[11] Menyah K, Wolde-Rufael Y. Energy consumption, pollutant emissions and economic growth in South Africa. Energy Economics 2010;32:1374–82.

[12] Ellis J, Winkler H, Corfee-Morlot J, Gagnon-Lebrun F. CDM taking stock and looking forward. Energy Policy 2007;35:15–28.
[13] IEA. CO_2 emissions from fuel combustion. Paris: OECD/IEA; 2008.
[14] Kankam Stephen, Boon Emmanuel K. Energy delivery and utilization for rural development: lessons from Northern Ghana. Energy for Sustainable Development 2009;13:212–8.
[15] Kapadia K. Productive uses of renewable energy: a review of four Bank-GEF Projects. Washington, DC: World Bank; 2004 (Accessed on 18th August, 2008).
[16] Global Network on Energy for Sustainable Development (GNESD). Reaching the millennium development goals and beyond: access to modern forms of energy as a prerequisite. United Nations Environment Programme. Denmark: Roskilde; 2007.
[17] Toman, M, Jemelkova, B . Energy and economic development: an assessment of the state of knowledge. Discussion Paper Series DP 03-13. Washington, DC: resources for the future; 2002.
[18] Sanya C, Sara L, Adrienne B, Andrew N, Elinor B. Energy-based economic development. Renewable and Sustainable Energy Reviews 2011;15:282–95.
[19] Kaygusuz K. Energy services and energy poverty for sustainable rural development. Renewable and Sustainable Energy Reviews 2011;15:936–47.
[20] Pereira MG, Freitas MAV, da Silva NF. Rural electrification and energy poverty: empirical evidences from Brazil. Renewable and Sustainable Energy Reviews 2010;14:1229–40.
[21] Nitin Agarwal, Anoop Kumar, Varun. Optimization of grid independent hybrid PV-diesel-battery system for power generation in remote villages of Uttar Pradesh, India, Energy for Sustainable Development, http://dx.doi.org/10.1016/j.esd.2013.02.002; 2013.
[22] Lanjouw JO, Mody A. Innovation and the international diffusion of environmentally responsive technology. Research Policy 1996;25:549–71.
[23] Mohammed YS, Mokhtar AS, Bashir N, Saidur R. An overview of agricultural biomass for decentralized rural energy in Ghana. Renewable and Sustainable Energy Reviews 2013;20:15–22.
[24] Mohammed YS, Mustafa MW, Bashir N, Mokhtar AS. Renewable energy resources for distributed power generation in Nigeria: a review of the potential. Renewable and Sustainable Energy Reviews 2013;22:257–68.
[25] Shyu C-W. End-users' experiences with electricity supply from stand-alone mini-grid solar PV power stations in rural areas. Energy for Sustainable Development 2013. http://dx.doi.org/10.1016/j.esd.2013.02.006.
[26] Mwakaje Agnes Godfrey. Dairy farming and biogas use in Rungwe district, South-west Tanzania: a study of opportunities and constraints. Renewable and Sustainable Energy Reviews 2008;12:2240–52.
[27] Mainali B, Silveira S. Alternative pathways for providing access to electricity in developing countries. Renewable Energy 2013;57:299–310.
[28] Lahimer AA, Alghoul MA, Yousif F, Razykov TM, Amin N, Sopian K. Research and development aspects on decentralized electrification options for rural household. Renewable and Sustainable Energy Reviews 2013;24:314–24.
[29] Jo´zef Paska Piotr, Biczel Mariusz. K1os, hybrid power systems—an effective way of utilising primary energy sources. Renewable Energy 2009;34:2414–21.
[30] Paska J, Biczel P, K1os M. Experience with hybrid power generating systems. In: Eighth international conference, electrical power quality and utilisation—EPQU'05. Cracow-Poland; September 21–23, 2005.
[31] Bajpai Prabodh, Dash Vaishalee. Hybrid renewable energy systems for power generation in stand-alone applications: a review. Renewable and Sustainable Energy Reviews 2012;16:2926–39.
[32] Moriana I, San Martiin I, Sanchis P. Wind-photovoltaic hybrid systems design. In: International symposium on power electronics electrical drives automation and motion (SPEEDAM); 2010. p. 610–615.
[33] Nelson DB, Nehrir MH, Wang C. Unit sizing of stand-alone hybrid wind/PV/fuel cell power generation systems. In: IEEE power engineering society gen meet; 2005. p. 2116–2122.
[34] Yamegueu D, Azoumah Y, Py X, Zongo N. Experimental study of electricity generation by solar PV/diesel hybrid systems without battery storage for off-grid areas. Renewable Energy 2011;36(6):1780–7.
[35] Wichert B. PV-diesel hybrid energy systems for remote area power generation—a review of current practice and future developments. Renewable & Sustainable Energy Reviews 1997;1(3):209–28.
[36] Hrayshat ES. Techno-economic analysis of autonomous hybrid photovoltaic-diesel-battery system. Energy for Sustainable Development 2009;13(3):143–50.
[37] Benoit P. Energy for Africa, sixth meeting of GFSE, Africa is energizing itself, Vienna, Austria; 2006.
[38] Karekezi S, Kithyoma W. Renewable energy in Africa: prospects and limits. ⟨http://www.un.org/esa/sustdev/sdissues/energy/op/nepadkarekezi.pdf⟩; 2003.
[39] Dasappa S. Potential of biomass energy for electricity generation in Sub-Saharan Africa. Energy for Sustainable Development 2011;15:203–13.
[40] Duku MH, Gu S, Hagan EB. A comprehensive review of biomass resources and biofuels potential in Ghana. Renewable and Sustainable Energy Reviews 2011;15:404–15.
[41] Felix M, Gheewala SH. A review of biomass energy dependency in Tanzania. Energy Procedia 2011;9:338–43.
[42] Kassenga GR. Promotion of renewable energy technologies in Tanzania. Resources, Conservation and Recycling 1997;19(4):257–63.
[43] Bingh LP. Opportunities for utilizing waste biomass for energy in Uganda. Oslo, Norway: University of Science and Technology; 110.
[44] Jingura RM, Matengaifa R. Optimization of biogas production by anaerobic digestion for sustainable energy development in Zimbabwe. Renewable and Sustainable Energy Reviews 2009;13:1116–20.
[45] Mkiramweni LLN, Mshoro IB. Estimating the potential for biogas production and applications in Morogoro region, Tanzania. Energy and Environment 2010;21:1357–67.
[46] Mwakaje AG. Dairy farming and biogas use in Rungwe district, South-west Tanzania: a study of opportunities and constraints. Renewable and Sustainable Energy Reviews 2008;12:2240–52.
[47] Mshandete AM, Parawira W. Biogas technology research in selected Sub-Saharan African countries-a review. African Journal of Biotechnology 2009;8:116–25.
[48] UNDP. UNDP world energy assessment: energy and the challenge of sustainability. New York, USA: United Nations Development Programs; 2000.
[49] HDIP. Pakistan energy yearbook 2003, 2004 & 2005. Islamabad, Pakistan: Ministry of Petroleum and Natural Resources, Government of Pakistan: Hydrocarbon Development Institute of Pakistan; 2005.
[50] World Trade Organisation, Trade policy review report by the secretariat. WT/TPR/S/194, ⟨http://www.wto.org/english/tratop_e/tpr_e/s194-00_e.doc⟩; December 2007.
[51] PhytoEnergy Development & Construction AG. Development of a bio-diesel industry in South Africa. In: Third German African energy Forum; 2008 April 23–24.
[52] Hagan, EB. Biofuels assessment report-ECOWAS sub-region. A paper presented at the AU/Brazil/UNIDO biofuels seminar in Africa, Addis Ababa, Ethiopia; 2007.
[53] Kerekezi, S. Biofuels in Eastern and Southern Africa. A paper presented at the AU/Brazil/UNIDO biofuels seminar in Africa, Addis Ababa, Ethiopia; 2007.
[54] Jumbe CBL, Msiska F BM, Madjera M. Biofuels development in Sub-Saharan Africa: are the policies conducive? Energy Policy 2009;37:4980–6.
[55] Demirbas MF, Balat M, Balat H. Potential contribution of biomass to the sustainable energy development. Energy Conversion and management 2009;50:1746–60.
[56] REN21. Renewables 2007 global status report. Renewable energy; 2007. p. 54.
[57] der Horst GH, Hovorka AJ. Reassessing the energy ladder: household energy use in Maun, Botswana. Energy Policy 2008;36(9):3333–44.
[58] Sambo, AS. Strategic development in renewable energy in Nigeria. In: International Association for Energy Economics. 21–24 June. San Francisco IAEE International Conference, 15–19; 2009.
[59] Department of Minerals and Energy. White paper on the energy policy of the Republic of South Africa; December1998.
[60] Bugaje IM. Renewable energy for sustainable development in Africa: a review. Renewable and Sustainable Energy Reviews 2006;10:603–12.
[61] FAO (Food and Agriculture Organization of the United Nations). Global forest resources assessment 2005—extent of forest resources. FAO forestry paper 147, Rome; 2005. p. 11–36.
[62] Kees Marlis, Feldmann Lisa. The role of donor organisations in promoting energy efficient cook stoves. Energy Policy 2011;39:7595–9.
[63] Adeoti O, Oyewole BA, Adegboyega TD. Solar photovoltaic-based home electrification system for rural development in Nigeria: domestic load assessment. Renewable Energy 2001;24:155–61.
[64] Chineke Theo Chidiezie, Ezike Fabian M. Political will and collaboration for electric power reform through renewable energy in Africa. Energy Policy 2010;38:678–84.
[65] Li J, Wang S. China solar PV report in 2007. Chinese Environmental Science Press; 2007.
[66] Changliang X, Zhanfeng S. Wind energy in China: current scenario and future perspectives. Renewable and Sustainable Energy Reviews 2009;13:1966–74.
[67] European Wind Energy Association. Delivering energy and climate solutions—EWEA 2007 annual report; 2008.
[68] Strobl E, Strobl RO. The distributional impact of large dams: evidence from cropland productivity in Africa. Journal of Development Economics 2011;96:432–50.
[69] Simiyu SM, Keller GR. Seismic monitoring of the Olkaria Geothermal area, Kenya Rift valley. Journal of Volcanology and Geothermal Research 2000;95:197–208.
[70] Gaast Wytze van der, Begg Katherine, Flamos Alexandros. Promoting sustainable energy technology transfers to developing countries through the CDM. Applied Energy 2009;86:230–6.
[71] Abanda FH, Ng′ombe A, Keivani R, Tah JHM. The link between renewable energy production and gross domestic product in Africa: a comparative study between 1980 and 2008. Renewable and Sustainable Energy Reviews 2012;16:2147–53.
[72] UNFCCC. The Kyoto Protocol, Article 12. In: Third conference of the parties to the UNFCCC; 10 December 1997, Kyoto, Japan.
[73] Amigun B, Sigamoney R, von Blottnitz H. Commercialisation of biofuel industry in Africa: a review. Renewable and Sustainable Energy Reviews 2008;12:690–711.
[74] Karekezi S, Kimani J. Status of power sector reform in Africa: impact on the poor. Energy Policy 2002;30:923–45.
[75] REN21: renewables global status report. Paris/Washington, DC: REN21 Secretariat/Worldwatch Institute; 2008:.Copyright© 2008 Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH; 2007.